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Sweetpotato vine management for confined food production in a space life-support system

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Abstract

Sweetpotato (*Ipomea batatas* L.) 'Whatley–Loretan' was developed for space life support by researchers at Tuskegee University for its highly productive, nutritious storage roots. This promising candidate space life-support crop has a sprawling habit and aggressive growth rate in favorable environments that demands substantial growing area. Shoot pruning is not a viable option for vine control because removal of the main shoot apex drastically inhibits storage-root initiation and development, and chemical growth retardants typically are not cleared for use with food crops. As part of a large effort by the NASA Specialized Center of Research and Training in Advanced Life Support to reduce equivalent system mass (ESM) for food production in space, the dilemma of vine management for sweetpotato was addressed in effort to conserve growth area without compromising root yield. Root yields from unbranched vines trained spirally around wire frames configured either in the shapes of cones or cylinders were similar to those from vines trained horizontally along the bench, but occupying only a small fraction of the bench area. This finding indicates that sweetpotato is highly adaptable to a variety of vine-training architectures. Planting a second plant in the growth container and training the two vines in opposite directions around frames enhanced root yield and number, but had little effect on average length of each vine or bench area occupied. Once again, root yields were similar for both configurations of wire support frames. The 3–4-month crop-production cycles for sweetpotato in the greenhouse spanned all seasons of multiple years during the course of the study, and although electric lighting was used for photoperiod control and to supplement photosynthetic light during low-light seasons, there still were differences in total light available across seasons. Light variations and other environmental differences among experiments in the greenhouse had more effects on vine length than on root yield. Average vine length correlated positively with total hours of daylight received across seasons, and responses for one plant per container were higher above a threshold duration of solar exposure, suggesting that the vines of two plants per container compete for available light. In addition to the adaptability of sweetpotato to various vine-training architectures and across seasons in terms of maintaining root productivity, the open, interior volumes of the support frames tested in this study will provide future opportunity to enhance sweetpotato root yield in space by adding novel interior lighting, such as from intracanopy arrays of light-emitting diodes. This work was sponsored by NASA grant NAG 5 1286.

Keywords: Bioregeneration; Controlled environment; *Ipomea batatas*; Light; Storage root; Training

1. Introduction

1.1. Sweetpotato for space life support

One of the challenges of next-generation space life support is developing a nutritionally balanced, sustainable

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vegetarian diet for space crews based upon a limited number of crop species. Traditional vegetarian diets anchored by legumes and cereal grains actually end up with too much dietary protein and too little fat, and if oily legumes such as peanut are used to satisfy these opposing requirements, separate calorie sources that lack additional protein are needed to make up needed carbohydrate calories (Mitchell et al., 1996). Sweetpotato is on the short list of food crop candidates for space life-support systems (Tibbitts and Alford, 1982) and produces large carbohydrate and antioxidant-rich storage roots (Woolfe, 1992). This crop has been proposed based on high productivity and low processing requirements, and is one of the few "sweet" components of the planned diet. Researchers at Tuskegee University have performed numerous studies with sweetpotato and selected productive, nutritious lines specifically for space life support (Mortley et al., 1991a). In addition to edible storage roots, young leaves and shoots also are edible as salad or cooked greens (Almazan et al., 1997).

In plans for food production systems for space, sweetpotato and white potato production fall into the middle category of foods requiring minimal processing (i.e. a microwave to cook), whereas near-term foods consist of salad crops and herbs that can be consumed raw, and long-term crops consist of foods such as wheat and soybean that require significant processing and processing equipment. Near-term food production systems will likely fly on the international space station, while mid- and long-term systems would be developed for longer-duration missions. Although sweetpotato roots and tender shoot parts can be consumed without additional processing, researchers have developed numerous additional processed foods from sweetpotato, including cereals and syrups (Woolfe, 1992).

Sweetpotato can be a highly productive crop, and while beneficial, this characteristic also provides challenges for optimizing edible biomass production while minimizing waste biomass accumulation within a restricted growth area. A previous sweetpotato study demonstrated that storage-root production is stimulated by restricting root volume (Massa et al., 2005). However, above-ground shoot production is copious, and branching vines aggressively invade all available growth space without some means of vine control. Researchers at Tuskegee demonstrated that reversing day and night temperature controls vine size in controlled environments (Mortley et al., 2000), but this technique also reduced root yield and required substantial energy. Not only must considerable heat from plant lighting be removed and cooler temperatures be maintained during the light period using the temperature-reversal approach, but heat must be added during the dark period for this warm-temperature crop (Jacobsen and Amsen, 1992). This issue exists regardless of whether solar or electric lighting is used.

In the crop module of a space life-support system, multiple crop species may have to be grown under common environmental conditions. Each crop may have different growth optima for temperature, light, relative humidity, and atmosphere. An issue for sweetpotato in such a generalized growth environment may be unwanted vine growth. Copious shoot production generates a large amount of inedible biomass that must be processed as waste in a closed-loop life-support system. Thus, it may be helpful to seek non-environmental methods to control sweetpotato vine growth without increasing energy cost. While chemical growth retardants might be an option for Earth-based, controlled-environment production of non-food crops, chemical control may not be the method of choice for a space life-support scenario, where launch mass must be minimized, consumables should be regenerable (Drysdale, 2001), and there may be a risk of exogenous chemicals accumulating in a closed system. Since environmental or chemical methods of vine control may not be practical or desirable for sweetpotato, cultural approaches may hold the answer. Previous studies by David et al. (1995) and Massa et al. (2005) demonstrated that pruning shoot tips of the main shoot caused significant reduction in the amount of storage root formed. The hypothesis driving the present research project was that sweetpotato shoot growth can be managed under a variety of environmental conditions using vine training without having a negative impact on root yield.

A related aspect of research for plant-based bioregenerative life support in space concerns the method of applying light to crop plants. At many space destinations targeted for human exploration and habitation, direct solar lighting may not be possible as the primary light source. Short daylengths, solar attenuation, very long dark periods, planetary dust occlusion, damaging UV and high-energy space radiation, micrometeorite impacts, and subterranean or shielded protective structures all may limit the amount of sunlight available to crops (Massa et al., 2006). For this reason, electric lighting, such as with light-emitting diodes (LEDs) and/or piping of concentrated solar light, may be alternatives to traditional crop-lighting scenarios (Jack et al., 2002; Massa et al., 2006). Efficient intracanopy LED lighting (Massa et al., 2006) likely will drive design of desired growth habits for crops, and the potential adaptability of sweetpotato vines to different vine-management strategies might allow flexibility in distributing light.

2. Materials and methods

2.1. Plant material and growth conditions

Seven vine-train cropping experiments including storage-root harvest were conducted in a greenhouse over different seasons. All experiments used cuttings of sweetpotato [*Ipomea batatas* (Lam.) L.] cv. 'Whatley–Loretan' (formerly breeding clone TU-82-155) developed at the George Washington Carver Agricultural Experiment Station, Tuskegee University, Tuskegee, AL for NASA's space life-support program. Cuttings of approximately 20 cm (3–4 nodes) in length were placed either in Scotts